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<p>The Strategic High-Altitude Radiance Code (SHARC) is a new computer code that calculates atmospheric radiation in the mesosphere and thermosphere. The initial version, SHARC-1, is available for distribution. This talk discusses the capabilities of this code and describes the new auroral model which will be incorporated in the next version. SHARC calculates radiance and transmittance for paths from 60 to 300 km altitude in the 2-40 μm spectral region. It models radiation due to NLTE (Non-Local Thermodynamic Equilibrium) molecular emissions which are the dominant sources at these altitudes.</p> <p><i>Keywords: infrared radiation, (KR)</i></p>					
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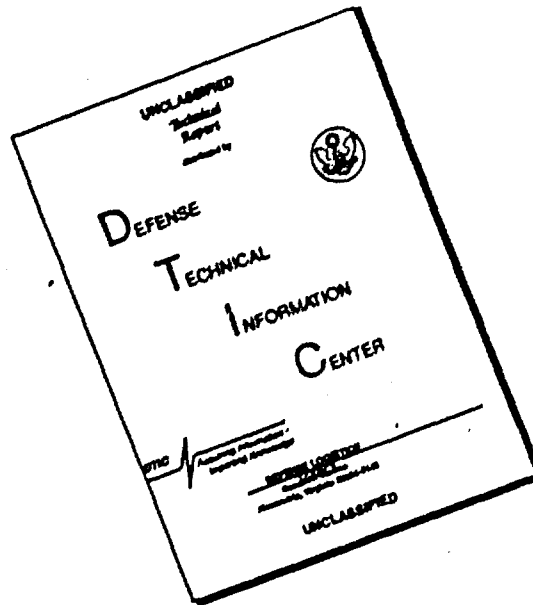
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CURRENT STATUS OF SHARC,
THE STRATEGIC HIGH ALTITUDE RADIANCE CODE,
AND
DESCRIPTION OF ITS NEW AURORAL MODULE

January 1990,

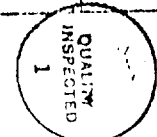
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Yap Analytics, Inc.

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ABSTRACT

The Strategic High-Altitude Radiance Code (SHARC) is a new computer code that calculates atmospheric radiation in the mesosphere and thermosphere. The initial version, SHARC-1, is available for distribution. This talk discusses the capabilities of this code and describes the new auroral model which will be incorporated in the next version. SHARC calculates radiance and transmittance for paths from 60 to 300 km altitude in the 2-40 μ m spectral region. It models radiation due to NLTE (Non-Local Thermodynamic Equilibrium) molecular emissions which are the dominant sources at these altitudes.



1. INTRODUCTION

SHARC, the Strategic High-Altitude Atmospheric Radiance Code, calculates background IR radiation at high altitudes.^(1,2) It includes

1. R. Sharma, A. Ratkowski, P. Acharya, L. Bernstein, J. Duff, J. Gruninger, D. Robertson, and R. Sundberg, "SHARC - An Atmospheric Model for High Altitudes (60-300 km)". Presented at the 1989 Meeting of the IRIS Targets, Backgrounds and Discrimination (February 1989).
2. R. Sharma, A. Ratkowski, R. Sundberg, J. Duff, L. Bernstein, P. Acharya, J. Gruninger, and D. Robertson, "Description of SHARC, The Strategic High-Altitude Radiation Code," Rpt. No. GL-TR-89-0229, Geophysics Laboratory, Hanscom AFB, MA 01731 (August 1989).

observer line-of-sight (LOS) paths above 60 km and calculates radiation from the five most important IR molecules, NO, CO, H₂O, O₃ & CO₂. This paper reports on work done on the model over the last twelve months. The initial version, SHARC-1, has been made available to the DOD community.⁽²⁾ The major upgrade has been development of an auroral module, which is based on the GL AARC (Auroral Atmospheric Radiation Code).⁽³⁾ It predicts enhancement due to electron dosing during auroral conditions. In the SHARC formulation radiation from the quiescent atmosphere around the aurora is also included.

At these altitudes, most atmospheric IR radiation comes from NLTE (Non-Local Thermodynamic Equilibrium) emissions of molecules in excited vibrational states. The NLTE conditions arise because higher vibrational states that result from chemical reactions in the upper atmosphere do not undergo enough collisions to restore thermal equilibrium before they radiate, e.g., their radiative lifetimes are less than or equal to their collisional lifetimes. Thus, the populations of each vibrational state must be calculated separately. Figure 1 show two calculations for the spectral radiance from the 15 μ m CO₂(ν_2) band for a space-based observer looking through the earth limb with a tangent altitude of 150 km. The NLTE radiation is much less than that from assuming (incorrectly) that the band is in LTE. Referring to temperatures instead of vibrational-state populations, the CO₂ band is vibrationally much colder than its kinetic temperature. The rotational states within each vibrational band are assumed to be in LTE;^(4,5) this has interesting ramifications which will be discussed below.

3. J. Winick, R. Picard, R. Joseph, R. Sharma, and P. Wintersteiner, "AARC: The Auroral Atmospheric Radiance Code," Rpt. No. AFGL-TR-87-0334, Air Force Geophysics Laboratory/OPE, Hanscom AFB, MA 01731 (November 1987) ADA202432.
4. Handbook of Geophysics and the Space Environment, A. S. Jursa Ed., Air Force Geophysics Laboratory, Hanscom AFB, MA 01731 (1985); copies obtained from NTIS, 5285 Port Royal Road, Springfield, VA 22161, ADA 167000.
5. R. Sharma, "Infrared Airglow," Progress in Atmospheric Physics, Eds. R. Rodrigo et al., Kluwer Academic Publishers (1988).

150 km LIMB RADIANCE

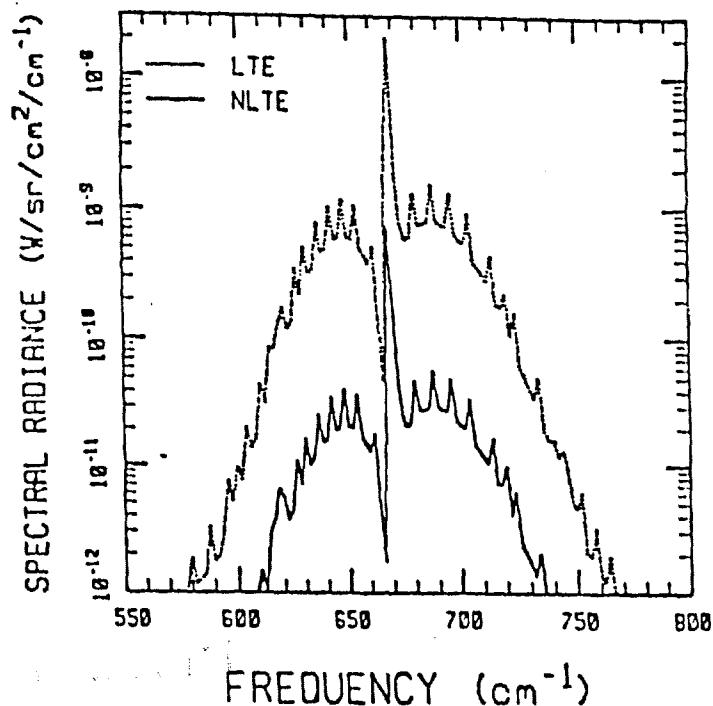


Figure 1. Calculation of the Spectral Radiance from the 15 μm $\text{CO}_2(\nu_2)$ Band Under Assumed LTE (Higher) and NLTE (Conditions). The NLTE Calculation is the Correct One.

2. SHARC-1 STATUS

SHARC-1 was described at the 1989 IRIS TBD Meeting.⁽¹⁾ This is the version which is now available to authorized users. Some of its basic features are:

- 60-300 km altitude regime,
- 2-40 μm with a spectral resolution of 0.1 cm^{-1} ,
- Adjustable chemical kinetic mechanisms and rates,
- User-selected molecular bands, and
- Arbitrary viewing geometries.

Arbitrary LOS paths are allowed, so long as they are above 60 km. The next version, scheduled for release at the end of the year, will extend down to 50 km. The data bases for the atmospheric profiles and the chemical

kinetics are based on those of the predecessor code HAIRM.(6,7) SHARC consists of six basic modules:

INPUT:

- Menu driven
- Interactive or batch mode

GEOMETRY (GEOM):

- Calculates observer LOS geometries

CHEMICAL KINETICS (CHEMKIN):

- Solves steady state rate equations

RADIATION TRANSFER (NEMESIS):

- Radiative excitation via layer-layer coupling
- Radiative trapping

SPECTRAL RADIATION TRANSPORT (SPCRAD):

- Single line NLTE equivalent-width formalism
- HITRAN line file augmented with NLTE O₃ lines

OUTPUT:

- Excited vibrational state populations & temperatures
- LOS Spectral and in-band radiance

An illustrative SHARC-1 calculation for a limb-viewing path with a tangent altitude of 80 km is shown in Fig. 2. The strongest radiators are the molecular bands of 4.3 μ m CO₂(ν_3), 15 μ m CO₂(ν_2) and 9.6 μ m O₃(ν_3). Other

6. T. Degges and A. D'Agati, "A User's Guide to the AFGL/ Visidyne High Altitude Infrared Radiance Model Computer Program," Rpt. No. AFGL-TR-85-0015, Air Force Geophysics Laboratory, Hanscom AFB, MA 01731 (1984) ADA161432.
7. R. Sundberg, D. Robertson, R. Sharma, and A. Ratkowski, "HAIRM-87 A High Altitude Infrared Radiance Model," Rpt. No. AFGL-TR-88-0014, Air Force Geophysics Laboratory, Hanscom AFB, MA 01731 (1988).

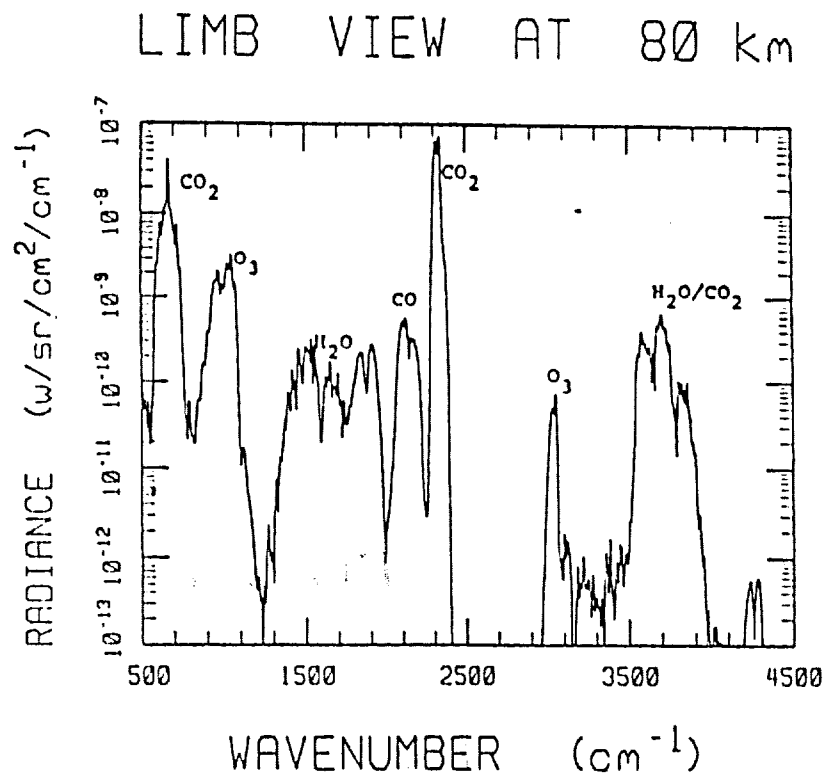


Figure 2. Atmospheric Spectral Radiance for a Limb Viewing Path with a Tangent Altitude of 80 km Under Daytime Conditions.

molecular bands are indicated in the figure. The $\text{CO}_2(\nu_3)$ band shows a strong diurnal effect with the daytime emissions being an order of magnitude stronger. This arises from solar excitation in the $\nu_3+\nu_1$ combination band at $2.7 \mu\text{m}$ and subsequent relaxation via energy transfer to the ν_3 band.⁽⁸⁾ The $\text{O}_3(\nu_3)$ band also shows diurnal structure, but it is stronger at night. In this case solar radiation breaks up the weakly bound O_3 to form O_2 and O . It reforms during the night. The radiation in the $16\text{--}30 \mu\text{m}$ spectral region is from rotational bands of ground-state H_2O .

8. For example, see R. Sharma and P. Wintersteiner, "CO₂ Component of Daytime Earth Limb Emission at 2.7 Micrometers," J. Geophys. Res., 90, 9789-9803 (1985), and references therein.

1976 STANDARD ATMOSPHERE

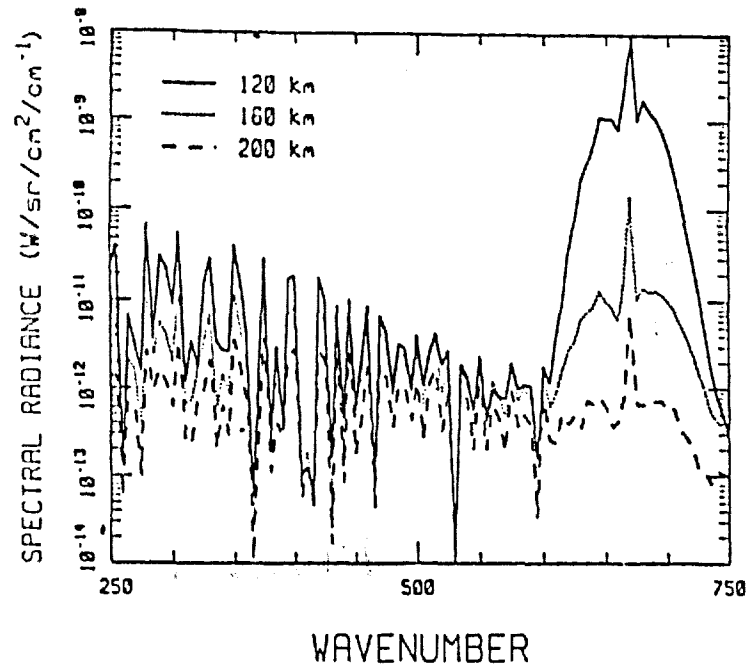


Figure 3. Atmospheric spectral Radiance for Limb Viewing Paths with Minimum Altitudes of 120, 160, and 200 km.

Three calculations for limb viewing with minimum LOS path altitudes of 120, 160 and 200 km are shown in Fig. 3. This figure illustrates some problems encountered in developing quantitative models for these high altitudes. The two strongest radiators in this spectral region are the $\text{CO}_2(\nu_2)$ band and rotational H_2O . The H_2O emissions are much weaker than those from CO_2 except at the highest altitude, where they are almost as strong. Determining whether this is a model artifact requires further study. As illustrated in Fig. 1 the CO_2 band is strongly NLTE, while rotational H_2O is modeled as LTE. It is generally estimated that there are sufficient collisions up to about 150 km altitude to maintain rotational LTE within each molecular vibrational state.^(4,5) There are neither data nor models currently available to describe at what altitudes and in what manner the rotational transitions depart from LTE. The rapidly increasing ambient temperature compensates for the decreasing H_2O number density and leads to only a slow decrease in radiation with altitude. The NLTE $\text{CO}_2(\nu_2)$

radiation decreases roughly with the product of the O and its number densities. At 200 km the CO₂ radiation has decreased to the same intensity as the H₂O rotational bands, if the latter are reasonably described by the LTE model. This figure illustrates some of the uncertainties and unknowns involved in predictive models at these high altitudes; measurements are very difficult, hence sparse and frequently questionable.

3. THE AURORA MODEL

The auroral module calculates the enhanced IR radiation from NO, CO₂ (4.3 μ m) and NO⁺, as well as contributions from unexcited ambient molecules. The module has the same user-friendly structure as SHARC-1 in that it has an interactive input module and all reactions and reaction rates are accessible to the user. The calculation begins with electron-deposition models for Class II, III and III+ auroras of finite size. The scientific approach used in AURORA is substantially based on AARC. (3)

The AURORA module is currently just being completed and works in conjunction with the other code modules. The AURORA module:

- calculates the deposition rate of the primary electrons,
- solves the time and energy dependent rate equations for the secondary electron distribution,
- solves the chemical rate equations for vibrational excitation of CO₂ and the formation of vibrationally excited NO and NO⁺, and then
- passes the vibrational state populations on to SPCRAD for calculating the spectral radiance for the LOS passing through the aurora.

The LOS information, which includes state populations and column densities for both auroral and ambient regions along the LOS, required a reformulated geometry module. Species populations for the undisturbed

background are calculated in the usual manner. Ambient and auroral populations are then stored for each layer along the LOS for use by the radiative transport module (SPCRAD) to calculate the path radiance and transmittance.

The time integration of electron dosing uses the Gear method for stiff differential equations, which is part of the Sandia CHEMKIN code⁽⁹⁾ incorporated in SHARC. The energy deposition model for primary electrons is based on work by Grün, Rees, and Strickland.⁽¹⁰⁻¹²⁾ As an example of the primary electron energy deposition model, the total ion pair production rate for a class III⁺ aurora is shown in Fig. 4. The actual routines were taken from AARC and modified to be consistent with the SHARC structure. In addition to the time-dependent auroral electron spectra, AURORA also calculates the time dependent production rates for the three auroral species. The chemical reactions and energy transfer processes used in these calculations are described in the AARC manual.⁽³⁾

From the ion pair production rate as a function of altitude, ionization efficiencies, secondary electron distributions and electronic and vibrational excitation rates for the major atmospheric constituents are calculated. An illustrative secondary electron distribution is shown in Fig. 5. An interesting feature is the large dip around 3 eV, which is due to secondary electrons transferring their energy to form vibrationally

9. R. Kee, J. Miller, and T. Jefferson, "CHEMKIN: Problem-Independent, Transportable, Fortran Chemical Kinetics Code Package," Sandia Rpt. No. SAND80-8003, Sandia National Laboratory, Livermore, CA 94550 (March 1980).
10. A. Grün, "Luminescenz-photometrische Messungen der Energieabsorption im Strahlungsfeld von Elektronenquellen Eindimensionaler Fall im Luft," Z. Naturforsch., 112a, 89 (1957)
11. M. Rees, "Auroral Ionization and Excitation by Incident Energetic Electrons," Planet. Space Sci., 111, 1209 (1964).
12. D. Strickland, D. Book, T. Coffey, and J. Fedder, "Transport Equation Techniques for the Deposition of Auroral Electrons," J. Geophys. Res., 181, 2755 (1976).

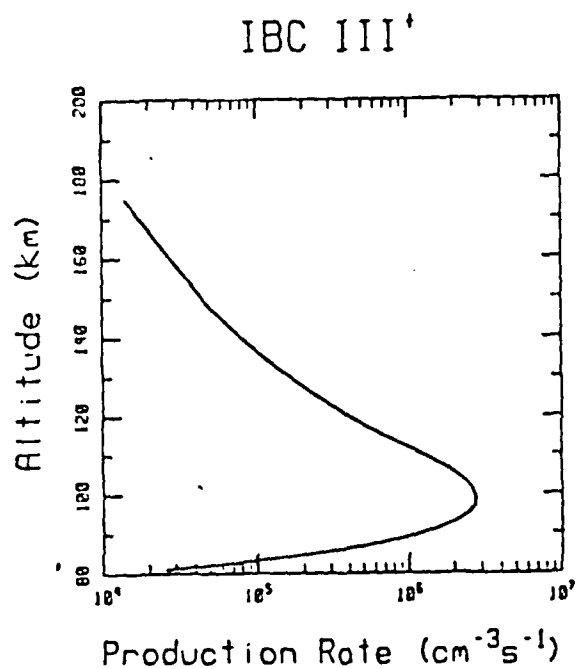


Figure 4. Ion Pair Production Rate for a Class III⁺ Aurora.

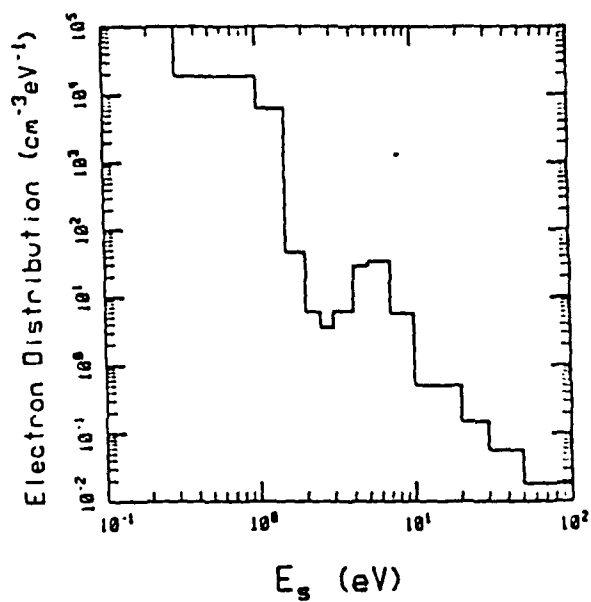


Figure 5. Steady State Secondary Electron Distribution at an Altitude of 100 km for a Class III⁺ Aurora.

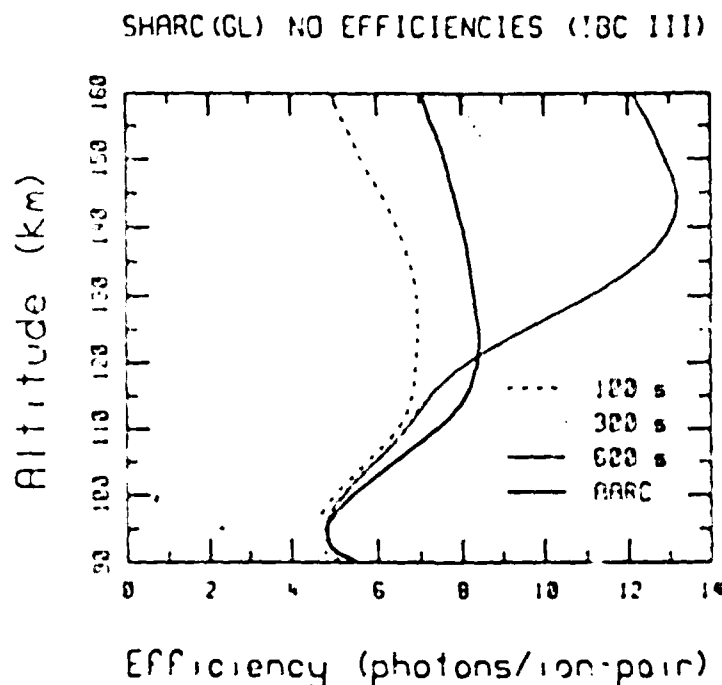


Figure 6. Comparison of Time Dependent SHARC and Steady State AARC Efficiencies for NO.

excited N_2 . The features and altitude dependence of secondary electron distributions have been discussed in detail elsewhere. (13)

Figures 6 and 7 compare SHARC and AARC steady state production efficiencies for NO and NO^+ in a Class III aurora. The calculated time evolution for NO production is also shown in Fig. 6. The difference between the SHARC and AARC predictions can be attributed to the use of a steady state solution to the rate equations in AARC. The steady state solution for NO requires the input of a NO number density profile appropriate for auroral conditions. However, the time dependent approach used in SHARC allows the formation of NO consistent with the chemical kinetics mechanism describing the aurora. Therefore, SHARC and AARC are in

13. O. Ashihara and K. Takayanagi, "Velocity Distribution of Ionospheric Low-Energy Electrons," Planet. Space Sci., 22, 1201 (1974).

NO⁺ EFFICIENCIES (IBC III)

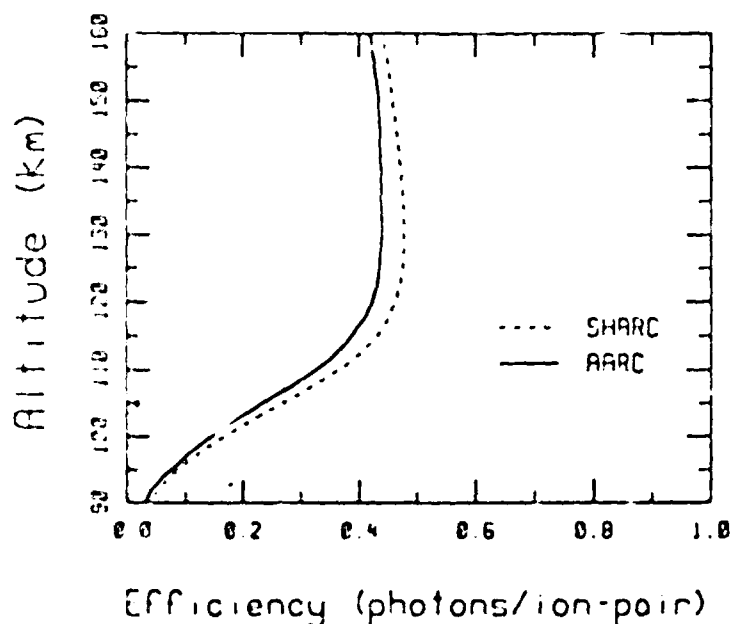


Figure 7 Comparison of Steady State SHARC and AARC Efficiencies for NO⁺.

substantial agreement below 120 km (where NO is in steady state), and are somewhat different above 120 km where SHARC indicates that time dependent effects are important. An illustrative calculation of aurorally enhanced NO and NO⁺ emission for a vertical path to space from 90 km is shown in Fig. 9. The calculation used an augmented HITRAN data file,⁽¹⁴⁾ which has additional lines for NO⁺ and vibrationally excited NO; these lines are taken from the data base furnished with AARC.

14. L. Rothman, R. Gamache, A. Goldman, L. Brown, R. Toth, H. Pickett, R. Poynter, J. Flaud, C. Camy-Peyret, A. Barbe, N. Husson, C. Rinsland, and M. Smith, "The HITRAN Database: 1986 Edition," Appl. Optics, **26**, 4058 (1987).

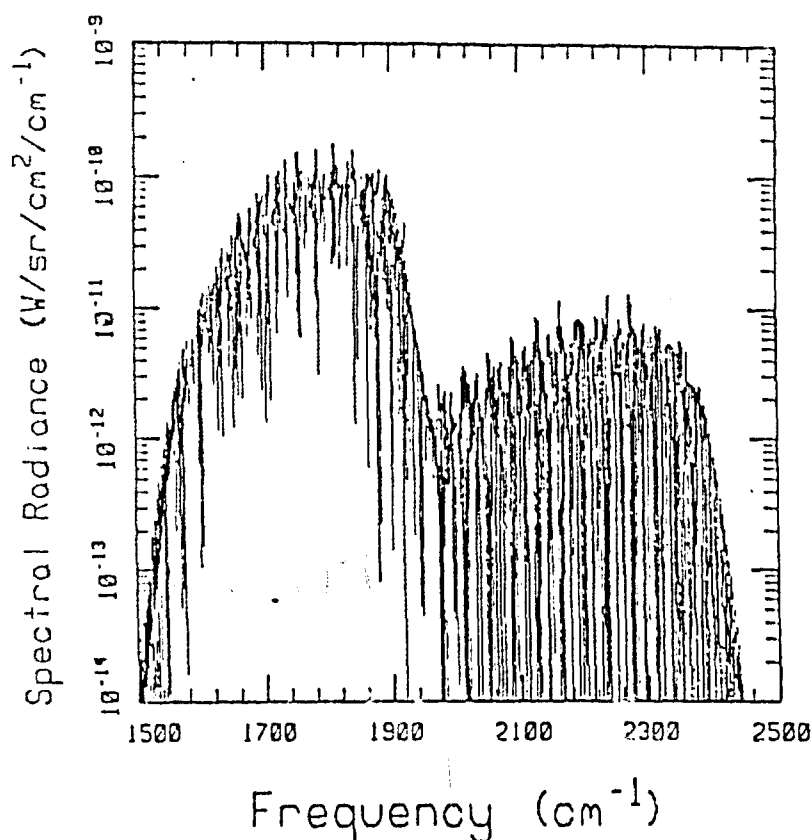


Figure 8. Spectral Radiance for a Class III Aurora. The Atmospheric Path is a Vertical One to Space from 90 km.

4. CONCLUSION

SHARC is a new computer code for calculating atmospheric NLTE radiance above 60 km altitude. It is now being distributed by GL/OPB; the point of contact is Dr. R Sharma. Initial validation of SHARC-1 has been accomplished by comparison to earlier AFGL codes, HAIRM⁽⁶⁾ and AARC.⁽³⁾ An auroral module, AURORA, has been incorporated into SHARC and is in the process of being tested and validated for release at the end of this year.

Additional upgrades are planned. These include:

- Isotopes of the major species, especially $^{13}\text{CO}_2$;
- Extension down to 50 km altitude;
- Upgrading the model atmospheres;

- Additional radiators, e.g., OH and O₂;
- A solar terminator model; and
- A model for radiance fluctuations due to spatial variations.

The first three items will be completed this year and distributed with the auroral option to SARC. The last three will be done in subsequent years.